COMPARISON OF HISTORIC AND RECENT GROWTH TRENDS IN OLD-GROWTH PONDEROSA PINE/DOUGLAS-FIR STANDS

COMPARISON OF HISTORIC AND RECENT GROWTH TRENDS IN OLD-GROWTH PONDEROSA PINE/DOUGLAS-FIR STANDS

Final Report: Research Joint Venture Agreement No. INT-94903-RJVA

Carl Fiedler, School of Forestry - UM
Brian Steele, Dept. of Math. Sci. - UM

29 September, 1997

INTRODUCTION

This report summarizes research conducted under Research Joint Venture Agreement No. INT-94903-RJVA. The general research objective was to analyze long-term growth trends and growth-climate relationships in old-growth ponderosa pine/Douglas-fir stands in western Montana. Specifically, four old-growth ponderosa pine/Douglas-fir stands were selected for this analysis, three on dry sites (Pseudotsuga menziesii/Calamagrostis rubescens h.t, Pinus ponderosa phase; Pfister et al. 1977), and one on a moist-site (Abies grandis/Linnaea borealis h.t.).

Determining the relationship of tree growth to climate is of interest to both ecologists and silviculturists. Thomas (1989) points out that one cannot speak knowledgeably about current growth declines (or increases) if long-term growth trends and relationships to climate have not been established -- an observation that highlights the significance of baseline dendroclimatological work.

A primary objective of dendroclimatic investigations is to identify the seasonality, sign (positive or negative), and strength of relationships between growth and climatic variables. For example, Taylor (1981) found that dendroclimatological

analysis can be a valuable tool in detecting and quantifying the importance of seasonal climatic factors to growth. Growth/climate models also provide insights into the growth response of individual tree species to climatic variation. Such information can be used to assess potential impacts of climatic change on productivity, range limits, and individual species dynamics in mixed-species stands.

Growth/climate investigations have been conducted at numerous locations in western North America, with most pioneering work and methodological developments coming from the American Southwest (Fritts 1974; Holmes 1983; 1992). Considerable recent work has also been conducted in the Pacific Northwest (Graumlich and Brubaker 1986; Peterson and Peterson 1994) and western Canada (Colenutt and Luckman 1991; Szeicz and MacDonald 1994). To date, however, tree-growth/climate relationships and associated dendroecological interpretations have not been developed for the western Montana portion of the Northern Rocky Mountains. This section of the Rocky Mountains has a unique and complex climate that contrasts sharply with the Central and Southern Rockies (Daubenmire 1943). Moist air masses moving east off the Pacific Ocean dominate winter weather patterns, resulting in mild, overcast winters with moderate to heavy snow accumulations at elevations above about 6000 ft. Summers are typically warm and dry, with drought common during the early July to late August period.

OBJECTIVES

The specific objectives of this study were to:

-- 1) analyze relationships between growth and climatic variables for the moist site old-growth stand (hereafter referred to as B4)

-- 2) compare and contrast growth-climate relationships for the moist site stand (B4) and the three dry site stands (hereafter referred to as L1, L2, and L3).

METHODS

We analyzed tree-ring chronologies previously collected for a study of age-class structure in old-growth pine/fir stands (Arno et al. 1995; Arno et al. 1996). Increment cores were measured for annual radial increments, from which annual basal area increments were calculated. The set of annual growth increments for a given tree is called a growth series (or a mean growth series, if aggregated for a stand).

Individual tree growth series were detrended by replacing the original values with standardized residuals obtained from fitting a cubic spline to each series (Cook and Peters 1981). The standardized residual series were then combined to produce a mean growth series for each species in each stand. Individual tree growth series are also of interest for some kinds of interpretations, and these individual series are sometimes (though not always) detrended. In this study, both approaches were used.

The purpose of detrending in growth/climate studies is to partition the total variation in growth response for a particular tree into two components. One component corresponds to combined short- and long-term trend associated with age and carry-over

effects such as climate, insect and disease infestation, and physical damage. The other corresponds to residual variation about the short- and long-term trend. Climatic effects on growth are best modeled as annual effects since the predominant source of variation in climate is annual. To ensure that estimates and test statistics were unbiased, we removed the short- and long-term components from residual variation. Then, residual variation was modeled as a function of climatic variables.

One of the drawbacks (usually ignored) of detrending is that growth trend cannot be detected in a detrended series. However, estimating growth trend was of interest in this study. This was accomplished by smoothing the original basal area increment (BAI) growth series for each tree, and retaining the smoothing values (which represent combined short- and long-term components). Smoothing was accomplished by fitting a general dynamic model with a time-invariant constant or intercept, and a time-varying parameter. The resulting smoothed series were then contemporaneously aggregated to provide an estimate of growth trend for the population of old-growth trees in stand B4.

The population of interest in stand B4 was defined to be all trees $\geq$100 years of age in 1894. From the available sample, 34 ponderosa pine and zero Douglas-fir were of sufficient age to be included in the analysis.

We modeled the mean growth series from the 34 trees in stand B4 as a function of one or more climatic variables constructed from mean monthly weather records. Data used in the analyses were monthly precipitation and monthly mean maximum temperature

records from the Hamilton, Montana, weather station for the period 1894-1991.

Climatic variables were constructed by combining monthly weather data into groupings based on documented phenological relationships in western Montana (Schmidt and Lotan 1980). Arbaugh and Peterson (1989) note that such groupings are useful in dendroecology for partitioning climate in physiologically-meaningful ways, while also reducing the number of variables to consider in model fitting. Variables were initially formed based on the above guidelines, and then modified during the fitting process to improve model fit. The final seasonal definitions were previous year's secondary growing season temperature ($_{py}$Jul-Aug$_{tmp}$) and precipitation ($_{py}$Jul-Aug$_{pct}$), previous year's post-growing season precipitation ($_{py}$Aug-Oct$_{pct}$), winter recharge season precipitation (Nov-Mar$_{pct}$), current year's pre-growing season temperature ($_{cy}$Mar-Apr$_{tmp}$) and precipitation ($_{cy}$Mar-Apr$_{pct}$), primary growing season temperature ($_{cy}$May-Jul$_{tmp}$) and precipitation ($_{cy}$May-Jul$_{pct}$), and secondary growing season temperature ($_{cy}$Jul-Aug$_{tmp}$) and precipitation ($_{cy}$Jul-Aug$_{pct}$). Climatic variables were standardized so that their relative importance could be assessed by comparing the values of their respective coefficients.

The Kalman filter recursion was used to model growth-climate relationships. Kalman filter applications in dendroclimatology have been presented by Visser and Molenaar (1988; 1990; 1992), Van Deusen (1990a; 1990b), and Peterson et al. (1993).

RESULTS

Growth Trend

The estimated mean growth trend for the 34 trees in the moist-site stand (B4) provides evidence of a decline in growth over time (Figure 1). The mean BAI in 1991 was less than two-thirds of the 1894 mean value.

For comparison, the mean growth response series (detrended) is shown in Figure 2. It is apparent that detrending, although necessary to allow modeling of growth/climate relationships, does indeed mask important growth trend information.

Growth/Climate Relationships

The growth/climate modeling effort, which used the mean growth response series (detrended) for stand B4, found growth to be significantly related to only two climatic variables -- previous year's August-October precipitation (${}_{py}Aug\text{-}Oct_{pct}$), and current year's pre-growing season temperature (${}_{cy}Mar\text{-}Apr_{tmp}$) (Table 1). Both the estimated mean growth response series and the climatic variables were standardized so that the relative importance of changes in climatic variables on growth could be assessed. The climatic variables significantly related to mean growth response in the three dry-site stands (L1, L2, L3) are also displayed in Table 1, for comparison purposes.

In contrast to the apparently modest climatic effects in the moist-site stand (B4), climatic effects on growth in the dry-site stands were substantial. Five climatic variables were significantly related to growth in the dry-site stands, versus only two in the moist-site stand. Furthermore, the two climatic

Figure 1. Mean BAI in stand B4 for the period 1894-1991, with 95 percent confidence interval.

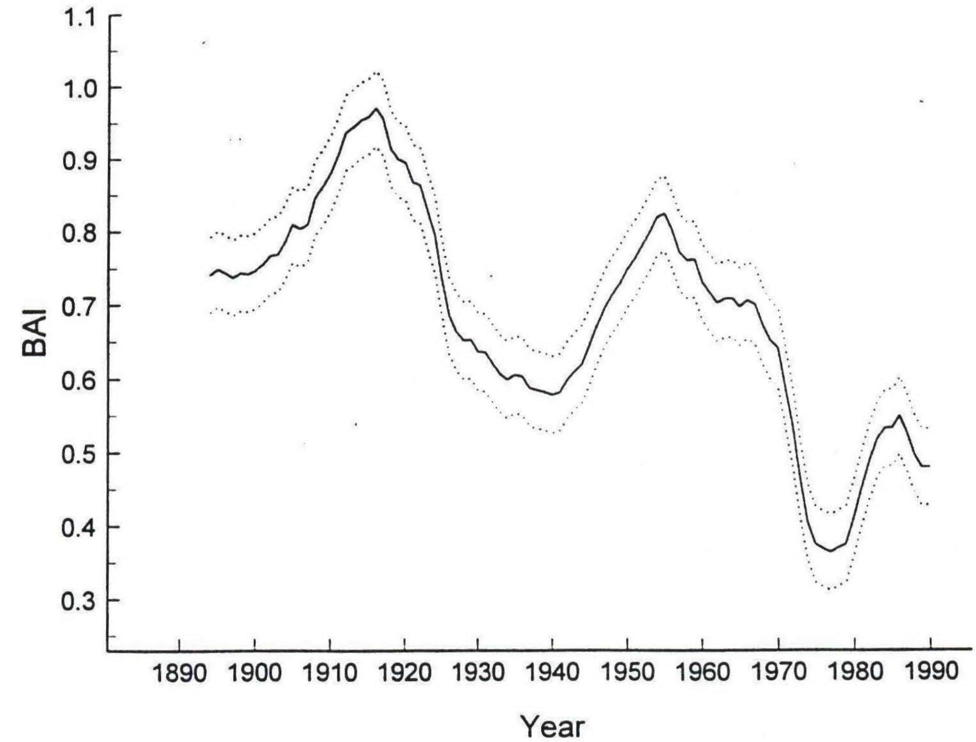
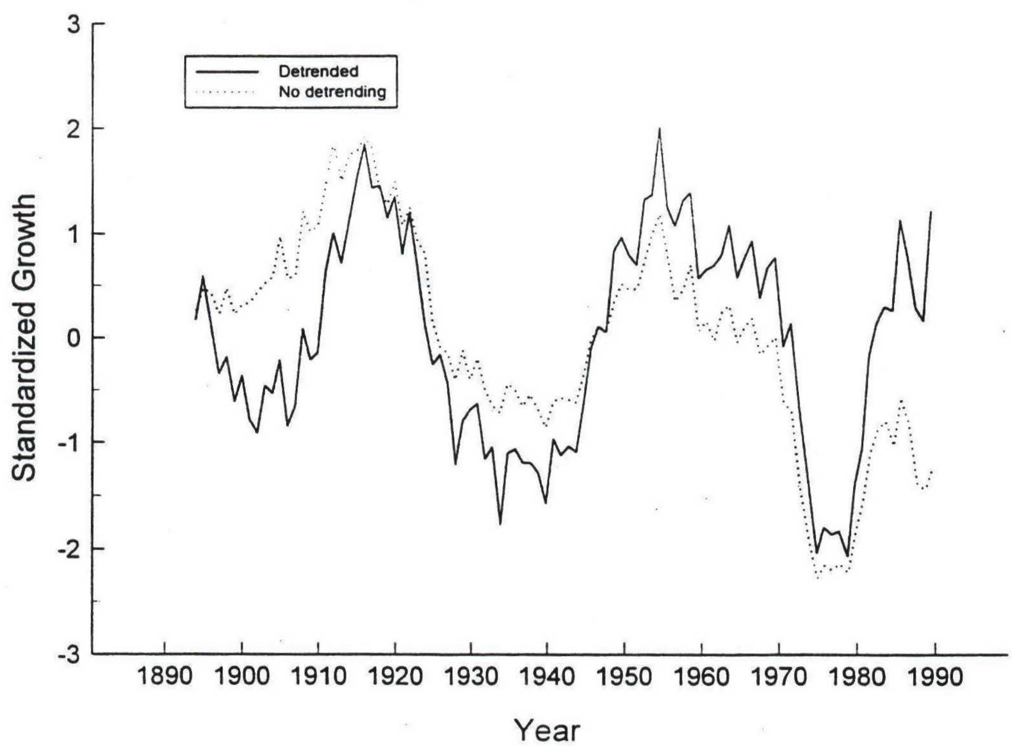


Figure 2. Standardized mean growth response series for stand B4, detrended and non-detrended.



variables significantly related to growth in both the dry- and moist-site stands ($_{py}$Aug-Oct$_{pct}$ and $_{cy}$Mar-Apr$_{tmp}$) had much larger coefficients in the dry-site stands, indicating a considerably stronger effect on growth.

Table 1. Coefficient estimates and associated standard errors for significant climatic variables in the models of estimated mean growth response for old-growth ponderosa pine in the moist-site stand (B4), and the three dry-site stands (L1, L2, L3).

	B4		L1		L2		L3	
Variable	Est.	SE	Est.	SE	Est.	SE	Est.	SE
$_{py}$Aug-Oct$_{pct}$	0.020	0.02	0.266	0.12	0.183	0.09	0.100	0.02
$_{cy}$Mar-Apr$_{tmp}$	0.021	0.02	0.174	0.05	0.214	0.03	0.058	0.30
$_{cy}$May-Jul$_{pct}$	0.140	0.03	0.145	0.03	0.075	0.02		
$_{cy}$May-Jul$_{tmp}$	-0.126	0.05	-0.238	0.03	-0.090	0.03		
$_{cy}$Jul-Aug$_{tmp}$	-0.140	0.05	-0.126	0.03	-0.267	0.06		

DISCUSSION

Mean growth response in stand B4 shows a relatively weak relationship to climatic variables over the last century. This suggests that factors contributing to growth decline since 1900 are endogeneous, rather than external to the stand. The decline in long-term growth may be partly due to an age effect (decreased growth with increasing age and senescence), since the 34 old-growth trees in this stand ranged from about 100 to 450 years old in 1894 (200 to 550 years old now). A sample correlation of BAI with age was conducted, and the results show a weak negative correlation (-0.28) between growth and age in stand B4 (Table 2).

Table 2. Sample correlation coefficients between BAI and age for the moist site stand (B4), and the three dry-site stands (L1, L2, L3).

Stand	Age
B4	-0.28
L1	-0.05
L2	-0.36
L3	-0.22

This provides evidence that trees are growing slower with increasing age. However, the decline in BAI from 1894 to 1991 occurred concurrent with the development of a vigorous fir understory/midstory component, which significantly reduces the amount of site resources available to the old-growth component. Indeed, development of the late successional component is a relatively recent phenomenon, since not a single Douglas-fir present in the stand today was 100 years of age in 1894. This density/structure/composition change in stand B4 has considerable import, since recent work in the Southwest suggests that smaller trees may exert significant competitive influence on old-growth ponderosa pine trees (Biondi 1996).

The weak relationship between growth and climatic variables in stand B4 (Table 1) suggests that the mild, moist conditions that typify this site (Abies grandis/Linnaea borealis h.t.) buffer effects of climatic extremes on growth. In contrast, climatic effects on growth in the dry-site stands were noticeably greater, both in terms of the number of seasonal climatic variables related to growth, as well as the strength of these

relationships. Precipitation received during the primary growing season ($_{cy}$May-Jul$_{pct}$) had a significant positive effect on tree growth on dry sites, whereas both primary and secondary growing season temperature ($_{cy}$May-Jul$_{tmp}$ and $_{cy}$Jul-Aug$_{tmp}$, respectively) had a significant negative effect. None of these three growing season climatic variables was significantly related to BAI of old-growth trees on moist sites.

MANAGEMENT IMPLICATIONS

The mean BAI decline of over one-third in stand B4 since 1894 is likely not just an age effect or climatic effect, but also a response to a developing and vigorous late-successional understory and midstory. Furthermore, few vigorous young pine are present in the understory of this stand to serve as future old-growth recruits to sustain the existing broad age-class distribution of pine. In fact, Arno et al. (1995) document that in 1993 there were no ponderosa pine in this stand less than 5 inches in diameter.

This stand has a relatively narrow window in terms of restoration options, since many old-growth trees are showing obvious signs of poor vigor, and few vigorous young pine are present to take their place. Given the existing declining condition, a carefully designed silvicultural cutting that significantly reduces stand density and Douglas-fir/true fir species composition appears to be the most prudent alternative available. The treatment would be designed to begin restoration aimed at approximating pre-1900 density, structure, and species

composition of this stand. A prescribed burning treatment should be integrated with the cutting treatment to kill understory firs, prepare seedbeds for regeneration, invigorate undergrowth species, and recycle immobilized nutrients. The ecological objectives of treatment would be to increase the vigor of the remaining old-growth pine component, and initiate regeneration of a new age class of ponderosa pine.

Stand B4, and others like it, are at a crossroads. The problem has previously been diagnosed and described (Arno et al. 1995; Arno et al. 1997); it has now been further quantified in this dendroclimatological/dendroecological study. The treatment needs (improvement selection cutting, thinning, complementary prescribed burning) have been identified (Fiedler et al. 1996), and prescription guidelines have been developed (Fiedler et al. 1997). The next logical step is treatment implementation.

LITERATURE CITED

Arbaugh, M.J. and Peterson, D.L. 1989. Variable selection in dendroclimatology: an example using simulated tree-ring series. For. Sci. 35: 294-302.

Arno, S.F., Scott, J.H., and Hartwell, M.G. 1995. Age-class structure of old-growth ponderosa pine/Douglas-fir stands and its relationship to fire history. USDA For. Serv. Res. Pap. INT-RP-481. 25 p.

Arno, S.F., Smith, H.Y., and Krebs, M.A. 1997. Old growth ponderosa pine and western larch stand structures: influences of pre-1900 fires and fire exclusion. USDA For. Serv. Res. Pap. INT-RP-495. 20 p.

Biondi, F. 1996. Decadal-scale dynamics at the Gus Pearson Natural Area: evidence for inverse (a)symmetric competition? Can. J. For. Res. 26: 1397-1406.

Colenutt, M.E. and Luckman, B.H. 1991. Dendrochronological investigation of *Larix lyallii* at Larch Valley, Alberta. Can. J. For. Res. 21: 1222-1233.

Cook, E.R. and Peters, K. 1981. The smoothing spline: a new approach to standardizing forest interior tree-ring width series for dendroclimatic studies. Tree-Ring Bull. 41: 45-53.

Daubenmire, R.F. 1943. Vegetational zonation in the Rocky Mountains. Bot. Rev. 9: 325-393.

Fiedler, C.E., Arno, S.F., and Harrington, M.G. 1996. Flexible silvicultural and prescribed burning approaches for improving health of ponderosa pine forests. USDA For. Serv. Gen. Tech. Rep. RM-GTR-278. p. 69-74.

Fiedler, C.E., Arno, S.F., and Harrington, M.G. 1997. Reintroducing fire in ponderosa pine/fir forests after a century of fire exclusion. Proc. of Tall Timbers Fire Ecol. Conf, No. 20. In press.

Fritts, H.C. 1974. Relationships in ring widths in arid-site conifers to variations in monthly temperature and precipitation. Ecol. Monogr. 44: 411-440.

Graumlich, L.J. and Brubaker, L.B. 1986. Reconstruction of annual temperature (1590-1979) for Longmire, Washington, derived from tree rings. Quat. Res. 25: 223-234.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bull. 43: 69-78.

Holmes, R.L. 1992. Dendrochronology program library. Lab. of Tree-Ring Research. Univ. of Arizona, Tucson. 35 p.

Peterson, D.L., Arbaugh, M.J., and Robinson, L.J. 1993. Effects of ozone and climate on ponderosa pine (Pinus ponderosa) growth in the Colorado Rockies. Can. J. For. Res. 23: 1750-1759.

Peterson, D.W. and Peterson, D.L. 1994. Effects of climate on radial growth of subalpine conifers in the North Cascade Mountains. Can. J. For. Res. 24: 1921-1932.

Pfister, R.D., Kovalchik, B.J., Arno, S.F. and Presby, R.C. 1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Rep. INT-34. 174 p.

Schmidt, W.C. and Lotan, J.E. 1980. Phenology of common forest flora of the Northern Rockies -- 1928 to 1937. USDA For. Serv. Res. Pap. INT-259. 20 p.

Szeicz, J.M. and MacDonald, G.M. 1994. Age-dependent tree-ring growth responses of subarctic white spruce to climate. Can. J. For. Res. 24: 120-132.

Taylor, R.M. 1981. Tree-ring analysis in forest productivity studies: an investigation of growth-climate relationships in the New Forest, Hampshire. J. Biogeog. 8: 293-312.

Thomas, C.E. 1989. Some observations regarding growth and yield of Southwestern ponderosa pine and dendro-ecological growth studies. p. 35-40 In: Conf. Proc. Multiresource management of ponderosa pine forests. Nov. 14-16. Flagstaff, AZ.

Van Duesen, P.C. 1990a. Evaluating time-dependent tree ring and climate relationships. J. Environ. Qual. 19: 481-488.

Van Duesen, P.C. 1990b. Popular formulations for modeling tree rings from climate: a unifying approach. J. Environ. Qual. 20: 823-827.

Visser, H., and Molenaar, J. 1988. Kalman filter analysis in dendroclimatology. Biometrics 44: 929-940.

Visser, H., and Molenaar, J. 1990. Estimating trends in tree-ring data. For. Sci. 36: 87-100.

Visser, H., and Molenaar, J. 1992. Estimating trends and stochastic response functions in dendroecology with an application to fir decline. For. Sci. 38: 221-234.